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The Affordance of Computer-Supportive Collaborative Learning in a Dynamics Course

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Affordance of Computer-Supported Collaborative Learning in a Dynamics Course

Introduction

Lecture is still a dominant instruction approach in undergraduate science, technology, engineering, and mathematics (STEM) classrooms [1]. However, STEM education communities have called for instructional reform to shift how we teach STEM subjects from transferring knowledge to students to engaging students actively in knowledge co-construction. To accomplish this goal, many educators use diverse learning activities, including diverse pedagogical alternatives to lecture, such as active learning [2], [3], blended learning [4], and collaborative learning [5]. Despite extensive research on teaching engineering in introductory (first year) courses using each learning approach, little research has focused on sophomore-level engineering sciences [6]. Research on undergraduate engineering student experiences in an integrated active, blended, and collaborative (ABC) learning context is even more uncommon.

A group of experienced engineering faculty at Purdue University (West Lafayette) developed an ABC learning environment, called *Freeform* in 2008. Since developing *Freeform*, this team has conducted a research project that provides the environment and its accompanying diverse resources to different universities in North America and South America. In Spring 2016, Prime (pseudonym) University decided to use *Freeform* for an undergraduate dynamics course.

The goal of this study was to examine how students perceived the *Freeform* learning environment at Prime University, whose school context differs from that of Purdue University. Much research has focused on estimating the quantitative impact of educational interventions (especially curricular) on student learning outcomes. However, previous research has paid less attention to how students perceive the potential affordances of the learning environment associated with an intervention. To better understand such perceptions of students, this study explored the following research question:

RQ: How do students perceive the affordances that an integrated active, blended, and collaborative learning environment offers?

Background

We began applying the *Freeform* environment in 2009. Based on the integrated advantage of the ABC learning approach, the *Freeform* system consists of the following components: in-person instruction with various active and collaborative learning activities, focused on problem solving; a dynamics lecturebook designed to be student friendly with lecture notes, including fundamental concepts, key example questions, and open-ended questions on wide white spaces that enable students to actively take notes and solve problems; online videos, covering worked examples [Figure 1], homework solutions [Figure 2], concept demonstrations and visualizations [Figure 3]; a course blog / discussion forum [Figure 4] that includes all of the course materials, as well as students' conversation threads used in collaborative learning; collaborative learning activities, such as group discussion and collaborative problem solving with peers in and out of classroom; and instructor office hours and a teaching assistant help room where students can ask questions and seek help related to dynamics. *Freeform* has been continuously refined based on the findings of our previous studies conducted in multiple dynamics courses in several distinct contexts, including teaching-focused and international universities, which differ from those of its initial implementation at Purdue University.

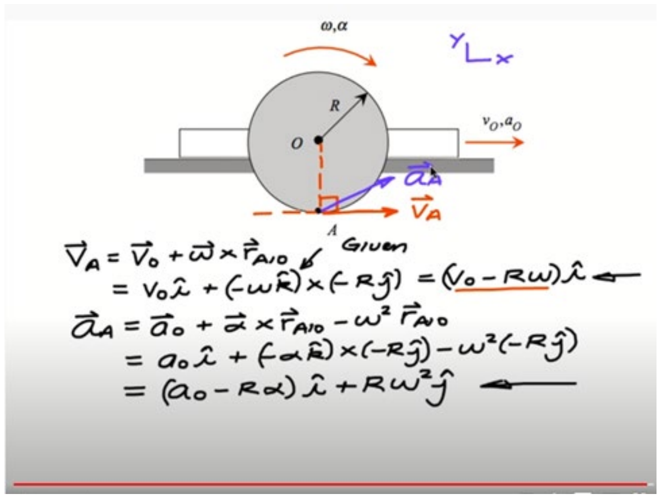

Figure 1. A screenshot from a representative example video.

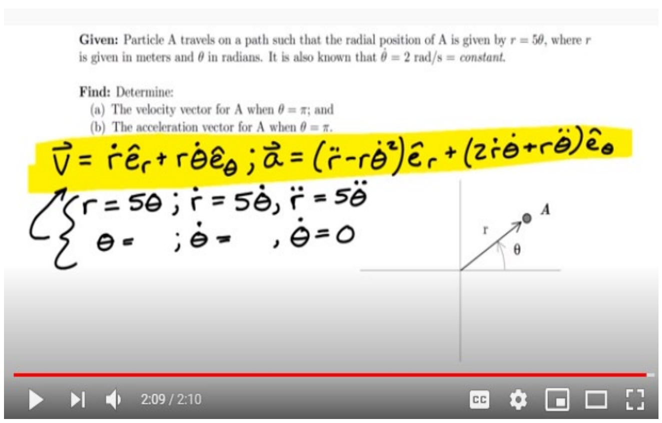

Figure 2. A screenshot from a representative homework solution video.

Figure 3. A screenshot from a representative Visualizing Mechanics video.

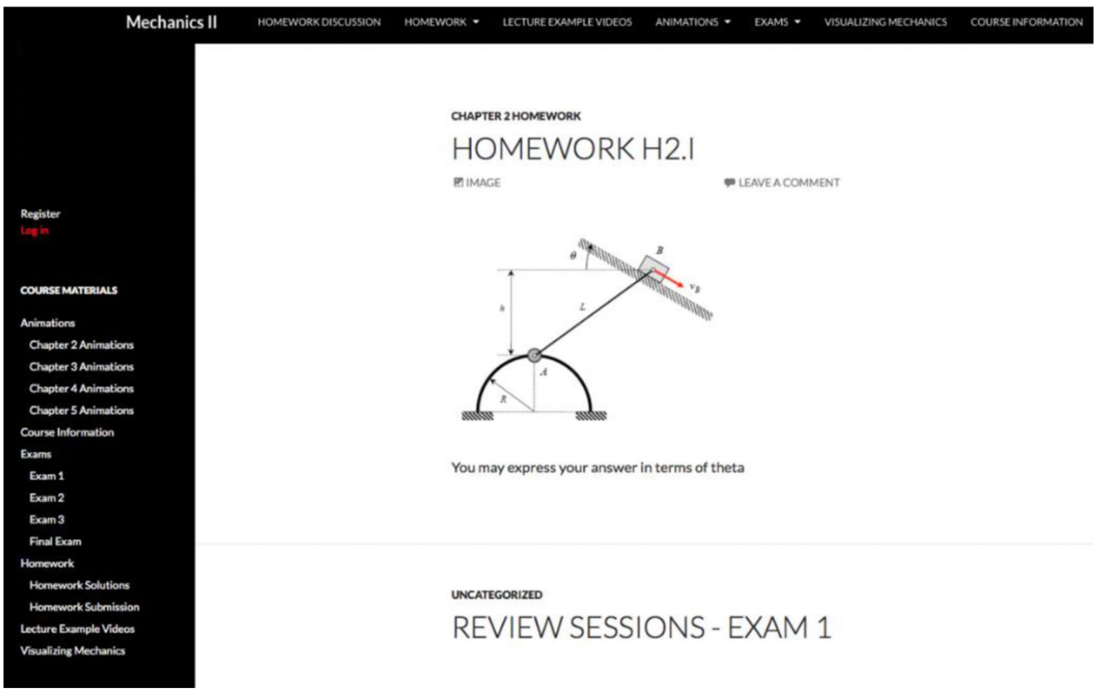

Figure 4. A screenshot from the Dynamics course blog / discussion forum.

In this article, we present findings from the *Freeform* dynamics course, focusing on the learning opportunities that students perceive in a new dynamics classroom environment, using the concept of "affordance." There is ample research evidence that students learn differently in different school settings, and our previous studies show that students engage with the *Freeform* system differently depending upon the local norms and pedagogical practices at their institution [7], [8]. In this paper, we examine the underlying mechanisms that contributed to how those students perceived the affordances of the *Freeform* learning environment in an undergraduate dynamics classroom.

Prime University is a public research-intensive university in Eastern Canada. In Fall 2016, its mechanical engineering department participated in our research and used the *Freeform* learning environment in a dynamics course, and they allowed us to examine how the *Freeform* dynamics was used in their context. At Prime University, the dynamics course had been notorious for its difficulty among undergraduate mechanical engineering students. Many students also failed the course in the previous semester. In Fall 2016, the dynamics course setting changed from that used in previous semesters to employ the *Freeform* system. The class size of the sampled dynamics course (50 students) was smaller than that seen in a typical Spring semester (approximately 150 students). This paper reports on our observations of this *Freeform* deployment.

Affordances of active, blended, and collaborative learning

The term "affordance" refers to features of an environment that provide humans with potential [9]. Norman later defined affordances in a manner particularly useful for education settings: affordances are *possible* actions that the user can take if they perceive a specific feature to be actionable [10]. That is, an individual's perception differentiates action from non-action related to a specific feature. Norman argues that the affordances of features are meaningful only when users perceive what the feature offers or why it might be useful. As the goal of our study is to examine students' *perceived* affordances of the *Freeform* learning environment for their learning, we use Norman's notion of affordances.

Blended learning continues to emerge as a prominent approach that can extend student learning opportunities beyond a traditional classroom-based approach by integrating face-to-face and online learning. Blended learning has a number of potential benefits, and multiple affordances depending on its construction and how users actually understand its utility [11] - [14]. A recent report showed that a large number of universities planned to build blended learning environments [15]. Previous meta-analysis studies have shown the benefits of blended learning for student learning [11], [16], [17]. However, other researchers have argued that the effects of blended learning on student learning should be examined based on a blended learning environment as a whole learning system, rather than separate blended learning techniques based on causal effects of research intervention [4]. In this paper, we consider *Freeform* as a learning system that offered active and collaborative learning opportunities to students in and out of the classroom.

Jeong and Hmelo-Silver proposed seven computer supported collaborative learning (CSCL) affordances of multiple technologies that support collaborative learning: "(1) engage in a joint task, (2) communicate, (3) share resources, (4) engage in productive collaborative learning processes, (5) engage in co-construction, (6) monitor and regulate collaborative learning, and (7) find and build groups and communities" [18, p. 249]. Jeong and Hmelo-Silver specified how diverse technologies could support collaborative learning along with their challenges, needs, and pedagogical examples for successful CSCL learning. However, the scope of such CSCL did not address the affordances of CSCL related to an individual student's learning, or active learning.

Methods

The goal of this study was to understand the students' perceived affordances of the *Freeform* learning environment in the Prime University institutional context. Thus, we adopt a constructivist paradigm to examine how participants perceived the situations studied [19]. Semi-structured interview is considered to be an effective qualitative research method to examine the participants' in-depth personal experience [20]. In our study, individual students' perspectives and experiences of the *Freeform* learning environment were probed in depth.

Research context

The *Freeform* system enacted at Prime University presented students the affordances of ABC learning structures and resources. The instructor designed the *Freeform* dynamics course using various blended learning techniques and tools, as Dziuban et al. described, such as a learning management system, online instructional videos, problem solution videos, Visualizing Mechanics videos, an online discussion board, and other online resources [4]. Among these blended learning techniques, worked example videos and homework solution videos were used to encourage students to engage in active learning opportunities by watching videos and reflecting on their problem-solving procedures [21], [22]. At Prime University, the instructor also used "Clicker" activities for whole class discussions, which provided students with collaborative learning opportunities in class [23], [24].

Participants

We interviewed nine students out of 50 students enrolled in dynamics at Prime University at the end of a semester in Fall 2016, each selected using purposeful sampling. In qualitative research, purposeful sampling is widely used to select participants [19]. Our sampling approach was to recruit the students who took the dynamics course across a semester and were willing to volunteer and share their learning experiences in the *Freeform* environment with our researchers. The participants volunteered for interviews, completed Institutional Review Board informed consent forms, and received compensation for their time with a $20 gift card to an online retailer. Though all of the participants majored in mechanical engineering, the participants' demographic backgrounds were diverse regarding race, gender, and school year. During the semester, the students studied dynamics in active and collaborative lessons within a blended learning environment, and we have reported extensively on the structure and resources of this learning environment in prior work [7], [8].

Data collection

Semi-structured interviews were conducted and ranged from 30 minutes to 45 minutes in length. We asked students open-ended questions to discuss school culture, student school life, self-identity, learning strategies, and their experience of courses, such as "How would you describe student culture here?", "How would you describe yourself?", and "How do you feel you learn best?" In addition, a significant portion of the interview focused on the individual participant's learning experience and their perception of the active, blended, and collaborative learning environment and its specific resources, as compared to those of other engineering courses. We asked questions like: "Tell me about your experience in this course", "How would you compare your experiences in this course to your experiences in your other courses?", and "How do you work with different resources?" The audio-recorded interviews were professionally transcribed in full and analyzed in qualitative data analysis software, NVivo. In this paper, we use pseudonyms to protect participant identity. The pseudonyms are used as descriptors, which do not represent the characteristics of the research participants.

Data analysis

We used thematic analysis [20] to analyze the students' interview transcripts and identified the salient themes and detailed patterns of the interview transcripts with the supervision of three senior engineering education researchers. To familiarize ourselves with the data, we conducted numerous readings of the interview transcripts. Our approach included both inductive and deductive analysis. We examined how students engaged with diverse *Freeform* resources designed to enhance active and collaborative learning in the blended learning environment. Next, open coding was conducted to generate initial codes that identified various types of the students' detailed experiences. Third, similar codes were grouped together, generating themes that described the salient patterns of the students' descriptions. A subsequent step involved reviewing the codes and created categories of themes by returning to the raw data and testing references. In the final step, the themes and subthemes were revised. These codes and themes were checked by three trained readers who analyzed student interview transcripts in our previous studies of multiple universities. Subsequently, we discussed disagreement and revised the codes. The goal of this analysis was to identify the affordances that the+
students perceived in the *Freeform* learning environment in a dynamics course.

Findings

Ubiquitous learning

All of the participants provided explanations that *Freeform* afforded the opportunities of ubiquitous learning with online video resources to them. The students described helpful resources within the *Freeform* structure that enhanced their learning. Within their perceptions, *Freeform* allowed them to access learning resources anywhere and at anytime. The participants described the online video resources as an effective means for obtaining additional learning outside of their classroom. Some of the participants described easily accessed online video resources as learning from an expert out of classrooms:

> We have the solutions to the problem in the lecturebook thing, but it's all videos, and they don't give the answer. It's really helpful because it's really nice to have someone explain it to me when I'm doing it at 2:00 am on a Saturday night. (Emily)

There was also a participant's perceived use of ubiquitous learning, focusing on the recorded dynamics classes that enabled the participant to watch the whole class without missing the professor's lesson or to watch a part of a class for their learning needs.

> I find it really, really useful, because I've never had a class that's been recorded before, because it's not the policy in engineering, I guess. So, sometimes I have to

> miss half of last class because I had a midterm scheduled and weird things. And I was able to catch up much more easily because the lecture recording exists, rather than having to ask for notes, and people…I prefer to be able to keep up with it on my own, and instead of having to rely on someone else. (Eva)

This statement appeals to one of the key points in many participants' descriptions. However, despite the positive experience of the whole class recordings, the participant's brief assumption, "it's not the policy in engineering," showed that students' perceived affordances of technologies in engineering classrooms are clearly placed in context in comparison to broader institutional policies and contexts. The institution plays a critical role in providing potential opportunities and cultural constraints [10], [25]. It shows the real affordances of the *Freeform* system in a classroom can be different from students' perceived affordances in engineering classrooms.

Multimodal learning

Many interviewees perceived the lecturebook and accompanying solution videos to be multimodal representations of the course material that supported their learning in this challenging engineering course. For example:

> Especially the *video homework assignments* and the *video examples*. Like, they saved my life, I feel. Like, having someone to tell you the steps and the right steps so that you don't get confused…If you don't understand what the teacher is saying in class, you go to the book. If you still don't understand, then, with the *blog*, you have someone in class telling you how to do it, then the *dynamics Freeform book* also explaining how to do it, and then you also had examples of *the videos* of someone saying, "Oh, well, you have to start with this. And since you know this, this is how you do it." So, I feel a hundred times better. (Amber)

Here, Amber perceived the affordance of multimodal resources combined with texts, images, audio, and video, which supported her different learning needs. Amber highlighted how various online videos and resources (italicized words in the quote) helped her solve confusing problems through reflection, "Oh, well, you have to start with this. And since you know this, this is how you do it." Overall, the combination of the lecturebook and online video resources covering examples, homework, and class lectures enabled students to access multiple, flexible, and credible multimodal resources. Moreover, similar accounts were given about how the online videos supported a student to solve homework problems; participants searched for *Freeform* resources with multiple representations by writing texts, drawing pictures, and watching videos as follows.

> I'll actually just sit with my computer and will print the questions because then I can draw, like drawing stuff and will try to do them as much as I can. And then when there's something I can't figure out the answer. I'll look at the videos if there are anything that looks like it. Well, I'll read the lecturebook first, and then if I can't figure it out, I will look on the [Prime dynamics] blog, and then if I can't

> figure it out, I'll look on the Purdue course blog and that's also a good resource. I like to have both. I don't know if we're supposed to use both. (Emily)

Students also described the benefit of videos that showed and explained problem solving processes and improved their knowledge construction. Some students particularly stated that they preferred a visual-oriented learning approach.

> Seeing things done, and then being able to develop a process from having seen it done, I guess. So, that's why I like those videos so much because you can watch them, see the process they use, because it is a pretty standard process, how you approach each question. And then, just ...Yeah, just seeing a lot of that being done will eventually ingrain it in your memory, I guess. That's how I learn usually, just repetition. Seeing it first and then doing it, but I feel like to get to the stage where you're able to do it, you have to have seen it quite a bit. (Lucas)

Furthermore, students contended that *Freeform* resources were well aligned with the dynamics course. In particular, the large set of problem solution videos (authored by the *Freeform* designers) were closely aligned with what they actually learned in a dynamics course.

> They're definitely more extensive than the average. I mean, for MECH 220 we have something like 150 example videos, I think, something like that. Whereas in other classes we might only get a couple or some YouTube videos that the professor suggests, but nothing as course specific as MECH 220. [These videos are] probably better because it's aimed right at MECH 220. The person who is speaking in the video or who is working in the video knows exactly who they're trying to address in the video. (Oscar)

Personalized learning

In the *Freeform* learning environment, diverse learning resources afford engineering students the opportunity to better engage in active and collaborative activities through personalized learning, which means that learners involve various learning opportunities to meet their individual needs, preferences, and conditions through multiple channels [26]. The clearly structured course was described as helping students to seek information through various types of learning resources. In traditional classroom contexts, students learned the same content knowledge, problem solving skills, and other engineering practices from their instructor. Textbooks and instructors' lessons in the classroom are the main learning resources, which makes students try to write perfect notes without missing their instructors' lecture notes during classes. However, these traditional conventions affected student learning as they used online resources clearly aligned with the dynamics course. Based on his personalized learning experience, Oscar articulated how the online video resources affected his previous learning approaches.

> I think I feel very prepared, because the way that the information is delivered to us it's very easy to organize and understand…I think it's changed the way that I use online resources. And also the way that I interact with my peers, because a lot of other assignments that we have to hand in are online assignments where you have an unlimited number of attempts and you're told immediately whether the answer is right or wrong. So having an assignment which we have to hand in for which we do not have a solution manual or general ideas or problems very similar to the problems that we have to answer in the assignments, then it forces me to go interact with my peers to actually see whether they have similar answers or different answers. (Oscar)

Here, Oscar enumerated how the organized resources improved his information seeking for learning and changed his previous learning approaches. He particularly articulated the unlimited, easy access to online resources without answer keys that fostered his interactions with peers as well as personal learning. In traditional engineering classrooms, students learn engineering in the same ways, learning from the same textbook, solving the same homework problems, and finding one correct answer to a problem. Many engineering students' primary learning goal is to find one correct answer to a problem within a short time rather than through learning procedures independently, which suggests a focus on expedient help seeking rather than improving their learning [27]. However, different from limited learning resources bound in physical classrooms, online video resources afford engineering students the opportunities to better engage in active and collaborative learning through personalized learning.

> I guess for this class, especially with the new lecturebook and stuff, it's almost on its own. The little textbook and stuff, there's lots of resources from that but I guess besides that, it's kind of doing its own thing. Some other classes have similar textbooks and all the people are doing similar things, this class it's almost like you're just doing something different from everyone else. (Keith)

> I'm a very visual person…In the YouTube videos, people showing how to do the problem will help me a lot. Visually seeing someone go through the problem and use each component of the problem to solve. I think that would be the best. (Amber)

Collaborative knowledge integration

Most students identified their instructor's use of the Classroom Response Systems ("Clickers"), as a useful and enjoyable enhancement to student learning through collaboration with peers and their instructor in a classroom.

> We have this thing in last class. That was really fun. That was kind of like a quiz thing. We had teams of like six or seven, and then we had like a series of questions, and then we answered them on the Clicker thing. Then, there was a

> winning team, who won [coffee] mugs. That was really fun. And I feel like people are really engaged and helping each other, especially within your team because you meet other people. I feel like that's cool. That's fun. (Emily)

Here, Emily appraised the Clicker activity as an excellent learning experience. In teacher-centered dynamics courses where instructors dominate class times to cover subject knowledge outlined in a course syllabus, engineering students rarely experience 'fun' and 'cool' learning opportunities. However, by engaging in problem solving with peers using Clickers, the students could participate in collaborative learning opportunities to develop their collaborative knowledge integration as well as individual intelligence by negotiating various ideas with peers.

In many undergraduate engineering classrooms, students focus on memorizing conceptual knowledge and copying detailed problem solution steps to meet their instructors' main teaching goal, transferring subject knowledge. However, in the *Freeform* classroom, the students have opportunities to learn their peers' different ideas, improve their conceptual understanding, and apply this understanding to real world problems. In this collaborative learning environment, student participation becomes active; student engagement is interactive.

> I think the last class we had, one of the questions was, "What is the force of friction on the tires of a rear drive car?" So, he [the instructor] had the answer, and then people were like, "But, shouldn't it be this [coordinate direction] way?" And people were coming up to the board and drawing their own diagrams. Then, he was drawing his diagrams, and they were talking. We didn't really come to a final answer because we took about 30 minutes…Sometimes we'll get into a larger discussion where people come down, there's a lot of different opinions coming from across the room about how it should be handled… you'll see some people who will be like, "Sir, can I come draw what I think on the board?" Then they'll draw, and everyone can see what they're thinking, and they'll be like, "Hey, maybe you did this wrong," or, "I don't think it works like that." It opens more of a discussion. (Ned)

> I actually work a lot with my friend and, actually, two other friends. We all do the homework problems separately. But then before it's due we often just will make sure that we all got the same answer at the end…And often we'll just look at each other's work and be like, "Oh, wow. Why did you do this?" And she's like, "Oh, well, zero, it should be equal to zero." Or something. And then we actually comment on like ... And at the end we actually end up with the same solution. The same answer. I feel like the other classes I would do all the problems alone and sometimes I wouldn't understand. But I wouldn't try to understand before handing it in. I would just kind of give up. Now that's actually much easier, I feel, to actually comprehend all the problems. (Amber)

Metacognition

The most often perceived affordance of the *Freeform* classroom environment is associated with metacognitive skills. According to students' statements, the structured resources encouraged the students to reflect on how they improve their learning by monitoring and adjusting their existing learning approaches. Students articulated their metacognitive approaches that adapted their studying strategies, as related to how to interact with their peers and how to solve dynamics problems, using online video resources in their structured blended learning contexts.

> This class has changed the way that you study or interact with your peers. I think I've learned how to do problems better, you know. The structure of the problems. Not just doing problems over and over until you memorize how to do the solution. But also do problems over and over so that you completely know how to do problems just by looking at the structure of it, looking "What are they asking for? What are they giving you? How can you do it now?" (Amber)

> My study process is a little different for this class, just because of the availability of those online videos. Well, what I usually would do is look at a problem, and then go back to the textbook and try and find out how to answer that problem, whereas for this (class), I'm more kind of "Watch the videos to try and learn the process, and then try and extrapolate that." (Lucas)

In these statements, the students perceived the affordance of metacognition in the *Freeform* classroom context that led to active and collaborative learning. First, Amber clearly showed that she used her metacognition to change her studying approach. For instance, Amber's reflective questions, "What are they asking for? What are they giving you? How can you do it now?", included a series of metacognitive skills, such as understanding the nature of a problem, identifying existing information, and recognizing her strengths and weaknesses to solve the problem. Next, Lucas specified how the online videos afforded him the opportunity to change his study process. Among Lucas's statements, "learning the process" and "extrapolate that" demonstrated his use of metacognitive skills. The online videos without answer keys enabled him to focus on learning the process and extend its application to find his own solution through reasoning. The *Freeform* environment integrated with diverse learning resources afforded each student numerous opportunities to exchange different types of feedback from peers, instructors, and self. This constant feedback from multiple sources enabled students to reflect on the nature of the problem, assess their knowledge and understanding of potential problem solutions, and decide on a final solution approach.

Multi-source feedback

All of the participants perceived the affordance of multi-source feedback in the learning environment. The students reported that various technology resources in the *Freeform* system enabled them to receive consistent feedback in and out of the classroom from multiple sources and perspectives: an instructor, peers, experts, and self. According to the students' descriptions, various resources provided them with different types of feedback. Lucas showed how online solution videos provided him with feedback in self-assessment to change his learning approach.

> This is a very good structured solution, I guess. I think it's pretty good. Yeah, a lot more video watching in this [class]…Usually what I would do in other classes is I would try and find past exams and see what the professor liked to ask, and try to deduce what he's going to ask in the future. Whereas, in this, I think I'm actually learning the subject material more, because you know how to do it. It's not like other classes, where there's ambiguity in what's going to be asked. You know the subjects, it'll come up. You know how to approach those problems because of the material that is available to us. (Lucas)

Here, Lucas stated that the *Freeform* online videos changed his test-oriented studying strategies to one in which he learns core concepts and procedures. In other classes, he used previous examination problems, focused on the detailed problem solving procedures, and memorized the problem approaches or solutions. However, in the *Freeform* class, Lucas watched the solution videos and studied dynamics more by himself. He reported that the available resource afforded him the opportunity to change his studying strategies to solve problems independently. Amber elaborated upon a series of multi-source feedback from her instructor through collaborative problem solving in a Clicker activity.

> The professor does a bunch of different examples just to get us ready. And then sometimes at the end he'll give us problems for us to do, and then…we have a little system where we can write in. It's for participation grade. We can write in our answer. And then we can see…what percentage people got it right and wrong. And if a lot of people got it wrong, then we probably might redo it. Then he'll explain it. (Amber)

According to Amber's explanation, her instructor used the Clicker activity as a formative assessment tool with feedback to improve student learning. Based on the students' answer to the Clicker question, the instructor assessed how much his students understood his lessons, recognized what students needed to learn more, and provided additional instructions through diverse feedback.

Emily also explained how her peers' feedback supported in-class group discussions by telling her story from her previous dynamics course.

> We usually do some fundamental questions, quiz questions. That is so helpful. It's really helpful. I think that the most useful part of the course pack [lecturebook], or what [the instructor] will say in front of the class is the discussion part, because I feel like it gives all the things that I make mistakes on. For example, last semester, for the whole semester I did not understand that the elastic coefficient only applies to the normal component. Can you believe that? That's the kind of thing

> that is discussed in the discussion…it's so important to me. (Emily)

Here, Emily emphasized the importance of in-class group discussions to improve her conceptual understanding of dynamics. When Emily took a dynamics course last semester, she misunderstood the concept of elastic coefficient and its application. However, in the *Freeform* classroom, group discussion with peers enabled her to understand "the elastic coefficient only applies to the normal component."

Active knowledge integration

The students reported that *Freeform* created a participatory learning environment with active knowledge integration. In a traditional lecture classroom, the students frequently had to spend a lot of time passively copying their instructor's lecture. However, in the *Freeform* classroom, the lecturebook with example videos enabled the students to focus on taking their own notes actively or constructively. For instance, Amber explained her active note-taking strategy without writing verbatim notes during her instructor's lecture.

> I love how it's structured…we have our book that I bring every class and I really base everything on. And in class all the PowerPoints come from the textbooks. That way I don't have to take any notes. And when we do problems in class, I don't have to recopy the questions, either. I can just write in the book. So that just makes it much more structured. When I have to go back and do problems, I have everything in this single book (lecturebook). Instead of some random notes everywhere and some problems that I can't even understand after class…I feel like the example videos and the course lecturebook are, like, the Bible. I use it also every day. I just read it over and over. Prepare myself for midterm assignments, I'm going to prepare myself for the final as well. I also use it all the time during class. So, I write [my notes] on it. I don't use any other type of notebook. (Amber)

Students also noted that the structure of the lecturebook also encouraged them to solve problems by themselves. They stated how technology would afford different learning opportunities to students. Eva explained how the lecturebook affected her approach to solve problems in dynamics.

> What's different from what we're doing now compared to what has been done in the past is, before they were just textbook questions, everybody would have the solution online. But now we can't. So, we actually have to do it. Which is really helpful, and I've been finding that I would do the problems. I'd work through it. It takes a couple hours during the week. Then, I'll do them again before the midterm. And I have a friend who said, 'all I did was doing the homework problems.' When we were doing them and then I did totally fine on the midterms because I understand the content as we go. (Eva)

Eva's statement showed that many undergraduate engineering students passively engaged in learning in other non-*Freeform* classroom settings. According to Eva, many engineering students, including her, choose an easier way to find solutions to problems for other courses (which use commercial textbooks whose solutions manuals are readily available online). Instead of spending hours solving a problem alone, they searched for other students' solutions and memorized them. However, when Eva solved problems in the lecturebook in the *Freeform* environment, for which no solutions manual exists online, she had to solve problems and study them with her peers to prepare for examinations.

Discussion

As compared to the traditional engineering classrooms, in the *Freeform* engineering classroom, the students interviewed showed greater agency, reflected on the useful learning opportunities of online-video resources in active and collaborative learning in and out of the classroom, and highlighted their values for student success in a challenging engineering course. Diverse online videos, covering examples, homework solutions, lectures, and visualization, fostered their active learning by assessing their knowledge, finding their learning needs, and solving problems. The *Freeform* learning environment benefitted students by empowering each to use diverse resources, and to collaborate with their peers in blended learning environments. Increased opportunities and engagement in individual and collaborative learning helped the students reflect on their own learning and enact positive learning experiences in a challenging course.

We contend that the findings of this study are closely related to the affordances that the active, blended, and collaborative learning environment provides for disciplinary learning in dynamics classroom contexts centered on complex problem solving integrated with mathematics and physics. When students learn a challenging engineering course in a traditional classroom, students focus on receiving their instructors' knowledge by watching the instructors' lectures, copying problem solutions on black or white boards, and taking verbatim notes. However, by providing diverse technology resources, the *Freeform* learning environment affords students the opportunity to consistently engage in active and collaborative learning.

In this study, diverse technology resources well aligned with the dynamics course helped students enhance their mastery of the challenging course content. Different types of technology resources provide diverse learning opportunities for individual students to assess the processes and products of their learning, choose relevant resources to meet their personal learning needs, and find final solutions. Such affordances of technologies also enabled students to collaborate with their peers in and out of classrooms. Although more complex factors are related to improving student learning outcomes in a classroom, instructors should design their learning resources (especially technology resources) to maximize flexible learning opportunities for diverse students' learning needs in current technology-rich learning environment.

Universities have invested immense financial resources and considerable effort to integrate cutting-edge technology in academic innovation, but their impacts on student learning remain weak. While universities could provide students with technologies that support learning based on the seven affordances of CSCL in general [18], the findings of our study reveal that students could perceive a wider scope of affordances of those technologies in specific disciplinary learning contexts [26]. To make students engaged in active and collaborative learning in blended learning environments, instructors need to design and revise their technology resources based on both the actual affordance and perceived affordances of technologies. Particularly, it is important for engineering instructors to recognize the diverse learning opportunities that a blended learning environment well-aligned with an engineering course enables students to engage in active and collaborative learning.

This study explored how undergraduate students' perceived affordances of an active, blended, and collaborative learning environment aligned with a dynamics course. Our findings demonstrate that course-specific active, blended, and collaborative learning structures enable undergraduate engineering students to perceive specific, beneficial CSCL affordances. The *Freeform* learning environment provides students with diverse active learning opportunities and increased collaboration in a blended learning environment for this challenging core engineering course. Our study suggests that the CSCL environment well aligned with an engineering course strongly encourages undergraduate students to reflect on their learning, meeting individual students' diverse and personalized learning needs. Despite considerable efforts to improve student learning in undergraduate engineering education, ineffective teaching, little belonging, and difficult engineering curricula have adversely affected undergraduate engineering students' educational and career paths [31], [32]. We suggest that a well-structured CSCL environment integrated with diverse online videos, including worked examples, homework problems, and visualized concepts can provide students with valuable opportunities to improve their active and collaborative learning experiences in and out of engineering classrooms.

Limitation and future research

Our qualitative study has the potential to contribute to blended learning environments where undergraduate students are studying with their peers in engineering classrooms, using diverse technology resources; however, the findings of this study have limitations. We analyzed individual interviews with nine students at the end of a semester without multiple data sources, such as their instructor, classroom observation, and other artifacts to verify our participants' accounts. Thus, integrating quantitative analysis, using multiple data sources, such as pre- and post-test to assess students' content knowledge, or pre- and post-survey for the students' learning experiences, will be beneficial for future research. Although we have examined students' perceived affordances of *Freeform* as an implemented learning environment, we did not focus on the potential relationship among students, an instructor, and the unique contexts of Prime University in this paper. However, our previous studies showed that overall, there is no difference in students' course grade among various groups of students who used *Freeform* resources differently [28], [29]. One study suggests that instructors who implement *Freeform* resources should cultivate students' self-efficacy or self-regulation skills rather than focus on encouraging the students' use of specific course resources [28]. The other study also suggests that instructors should implement an instructional approach to meet the individual students' diverse needs and preferences [29]. To this end, future research will apply the abbreviated Dynamics Concept Inventory (aDCI) [30] to examine an instructor's effect on student academic performance in the specific context of Prime University.

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